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The DES-Model. A Simulation Model of the Danish Energy System

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The DES-Model

A simulation model of the Danish Energy System

Poul Erik Grohnheit and Peter Skjerk Christensen

THE DES-MODEL

A Simulation Model of the Danish Energy System

by Poul Erik Grohnheit and Peter Skjerk Christensen

Abstract. The DES-Model is designed for a long-term description of the Danish energy system. Given the demand for useful energy in various sectors, and given development plans for the conversion and distribution system, the annual primary energy requirement is calculated, together with the costs for fuel, investment, operation and maintenance. In this report we present a survey of the main features of the program for the model, and a description of the model-structure which was used for the Danish Energy Plan 1981. The essential parts of this model are (1) the simulation of the electricity generating system, which includes combined heat and power, and (2) the structure and the efficiencies of the space heating system.

EDB descriptors: COMPUTERIZED SIMULATIONS; DENMARK; DUAL-PURPOSE POWER PLANTS; ENERGY DEMAND; ENERGY MODELS; PLANNING; POWER SYSTEMS; SPACE HEATING

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1 INTRODUCTION

The DES-Model is designed for a long-term description of the Danish energy system. Given the demand for useful energy in various sectors, and given development plans for the conversion and distribution system, the annual primary energy requirement is calculated together with the fuel costs, and the costs of investments, operation and maintenance for the energy system.

Part of the model was originally developed by the electrical utility ELKRAFT in the early 70's and named Long-term Planning System LPS). The purpose of this model was the simulation of the operation of a system of power stations that includes CHP (Combined Heat and Power Generation), together with a calculation of the investment and running costs.

This model was redesigned and extended by the Energy Systems Group(ESG) at Risø National Laboratory (1979) for use in a study of electrical heating, by adding a section which calculates the economic consequences of the demand for useful energy, with CHP, natural gas and electrical heating as alternative modes of space heating. Another version of the model was used for a study of the economic consequences of the introduction of nuclear power in Denmark undertaken by the Danish Economic Council in 1980.

The version of the model presented in this report corresponds to that used in the Danish Energy Plan 1981 (EP-81) to describe the various scenarios for energy consumption and the energy supply system. During this work the model structure was redesigned in order to provide the policy-maker with a flexible and easily understandable tool for translating energy demand

forecasts into primary energy requirement and its economic consequences.

In this report the essential part of the elements of the system necessary to construct and run a model are described. In chapter 2 the main features of the computer program are described. The DES-program contains the elements and facilities for building a model-structure consisting of input data, model-phases for the calculating, and lay-out for output. The model-structure for the EP-81 study is described in chapter 3, and a simplified partial model is illustrated in appendix A. The sub-model for the electricity generating system is described in chapter 4, and the sub-model for the space-heating system in chapter 5. The efficiency of CHP, which is a crucial parameter connecting these two systems, is described in appendix B. Finally in chapter 6 some examples of application are given.

2 THE DES-PROGRAM

The DES-program can be described as a mixture of an interpreter, which handles simple arithmetic expressions written by the user, a collections of functions describing more complex relations, and a data-base handling system with input and output facilities. The elementary unit of the system is called an account, and for each account annual values are stored for a number of years.

The program-facilities used for building a model structure consist of the following elements:

- up to 3000 accounts for a maximum of 40 years
- assignments, i.e. simple arithmetic expressions for the accounts
- a number of functions, i.e. more complex relations between accounts for one or more years
- routines for input data
- routines for output lay-out

These elements specified by the user are stored in a system file. The model structure may be of any complexity, as the programme includes facilities to transfer the values of an account from another system file, and to add or subtract the values from two system files. Thus a very complex system may be constructed from a number of separate modules with a few interface accounts, each module observing the limitations of the program.

The functions mentioned above are relations between two or more accounts for a single year or the whole planning period, e.g. calculation of present values of future payments. The most complex of these functions is the simulation model for electricity and CHP. This function requires data giving a detailed description of the electricity generating system:

- the total demand for electricity and its variations
- the demand for heat in each heat region, i.e. areas with a district heating grid supplied by CHP
- fuel prices
- for each power station: parameters for fuel type, maximum power, efficiency, availability, operating costs, heat production and heat region.

The simulation gives as results the electricity production and running costs of groups of power stations for each fuel type, and the heat production in each heat region. The simulation model is described in chapter 4.

The DES-model is divided into model-phases, which are logical units. A phase may consist of any of the elements mentioned above, and may be calculated separately or in line with other phases. This is a convenient way to break up a large model, or to make partial studies, e.g. parameter studies.

The basic concepts of the DES-program is further described in appendix A, and an example of the construction and running of a simplified partial model is shown.

The DES-program is written in FORTRAN 66 and implemented on the Burroughs B7800 computer at Risø.

3 MODEL STRUCTURE

3.1. Model-phases and data.

Figure 3.1 shows a simplified description of the structure of the DES-model which was used for the EP-81 study.

The blocks denote model-phases consisting of basic parameters, assignments and functions.

The circles denote exogenous input data or output tables, etc. The input data consist of forecasts and scenario parameters. Scenarios may be defined by variations of these data.

3.2. Electricity sector.

In Phase 1 a description of the stock of power stations for each year in the planning period is established. Old units are taken out and new units are put into operation according to a development plan.

In Phase 2 production by windmills and biogas installations are subtracted from the total electricity demand, and the required electricity production from thermal stations is found. Then the simulation model is run.

These phases are applied for each of the two electricity generating systems in Denmark (east and west of the Great Belt). The results are aggregated in Phase 3, and primary energy requirements are calculated together with the annual expenditure for investment, fuel, operation and maintenance. This part of the model was used as a separate model for the economic analysis of the electricity generating system.

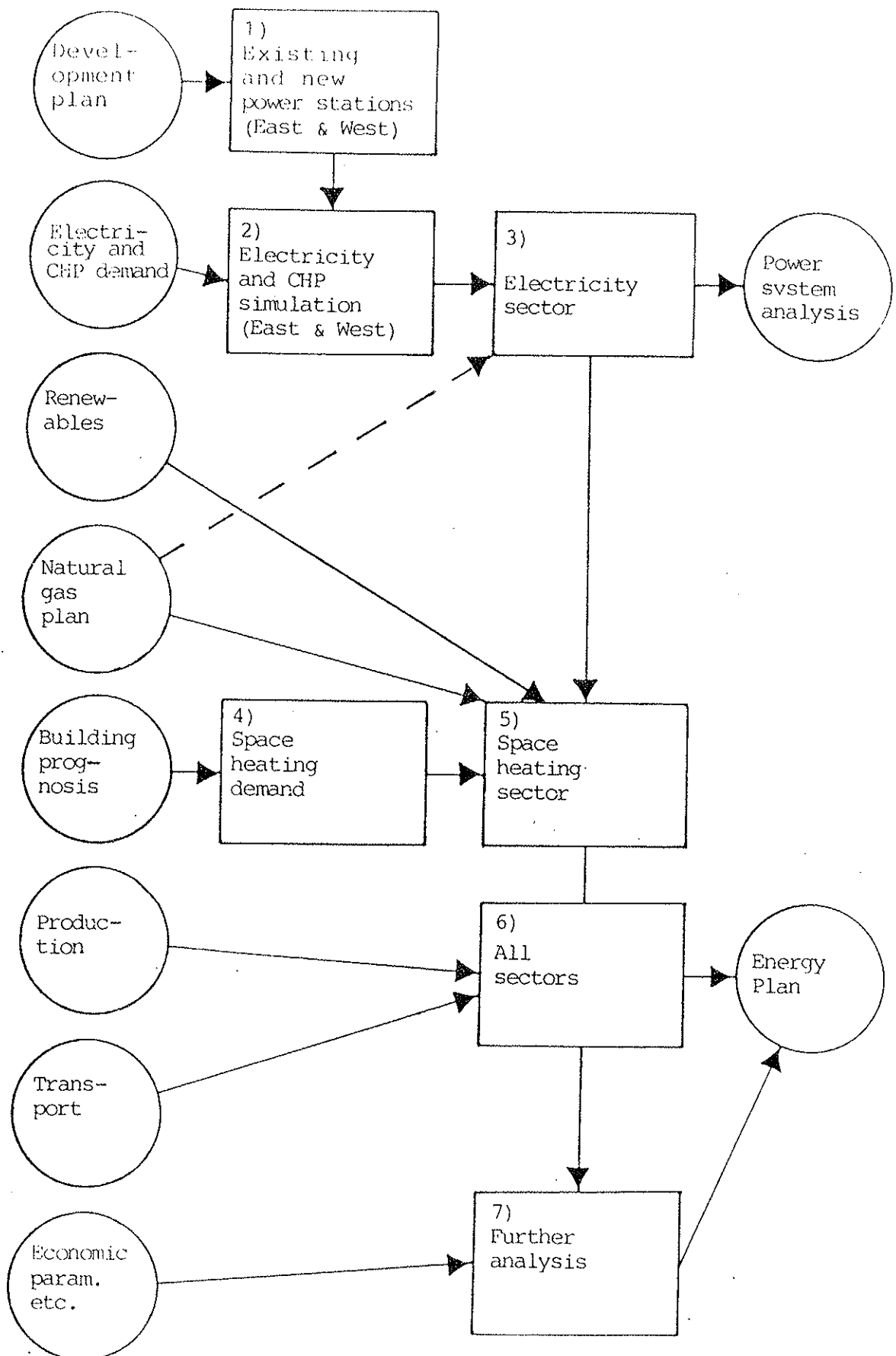


Figure 3.1. Main structure of the DES-model.

3.3. Space heating sector.

Phase 4 is a module in which the space-heating demand is calculated as the product of the forecasts for future building areas and for unit demand for useful energy per m^2 in existing and new buildings of various kinds and uses.

The distribution of heating forms and primary energy requirements for space heating are calculated in Phase 5. The supply of district heating from CHP, natural gas and waste incineration, etc. is known from the electricity sector of the model, or is provided exogenously. The rest of the supply for district heating is covered by fuel-oil (heavy oil).

For single-family houses the numbers of installations for district heating, electrical heating, natural gas, and renewables (wind, biogas, straw, heat-pumps, etc.) are given as forecasts. The rest of the houses are heated by oil burners supplied by gas-oil. Other buildings not connected to the district heating grid are supplied either by fuel-oil or by gas-oil.

The space heating sector is explained in details in chapter 5.

3.4. Primary energy requirement and total costs.

The fuel demands in the production and transport section are added in Phase 6, and the primary energy requirement for all sectors by fuel types is found together with annual costs for investment, fuel and operation and maintenance.

Phase 7 contains assignments, functions and parameters for further analysis, e.g. present values of expenditure, or employment and foreign trade consequences.

4 SIMULATION OF THE ELECTRICITY GENERATING SYSTEM INCLUDING COMBINED HEAT AND POWER

The simulation of the combined heat and power production is based on the following features:

- the power and heat demands are represented by load duration curves given as a summer and a winter part
- the maximum demand and the load factor are specified
- the production system is described by simplified data for the individual turbo-generator sets e.g. maximum electricity and heat output, specific heat rate, necessary man-power and so on.
- fuel and labour costs.

In the following sections a more detailed description is given.

4.1. Power and heat demand.

The simulation model is designed for use in long-term planning studies, which means that a day-to-day commitment taking into account the hourly variation of the demand has little interest. On the contrary, a quick, reasonably accurate calculation of the annual fuel and operation costs of the system is more important; and it is known by experience that the representation by load duration curves gives results good enough for this purpose, if they are used with some care.

The load duration curves for electricity for summer and winter may be specified with up to six points each, whereas the curves for heat are assumed flat and thus only the heat demands summer and winter are needed. It is possible to take into account changes in electricity demand over time by defining load duration

curves for specific periods. Thus the load duration curve may characterize a scenario, e.g. a load duration curve for a widespread use of electric storage heating may be introduced.

As the load duration curves for electricity are given in a normalized form, the maximum power and the load factor (i.e. average power divided by maximum power) have to be specified, the product of the two being the energy delivered. These numbers may depend on time as specified in the data.

4.2. The electricity generating system.

Power is produced at power plants by 3 types of turbines:

- condensing turbines without co-production of heat
- back-pressure turbines producing power and heat in a fixed relation given by the technical lay-out of the turbine
- pass-out turbines which allow both condensing and back-pressure production, and thus a flexible combination of power and heat.

The individual power unit is described by several technical and economic parameters, of which some are seen in figure 4.1. Only the most important parameters will be mentioned:

The unit is characterized by

- the maximum electrical and heat output (in the case of a condensing turbine $h_{\max} = 0$)
- the connection between minimum power and heat, c_m
- the connection between maximum power and heat, c_v
- the efficiencies as a condensing or a back-pressure turbine

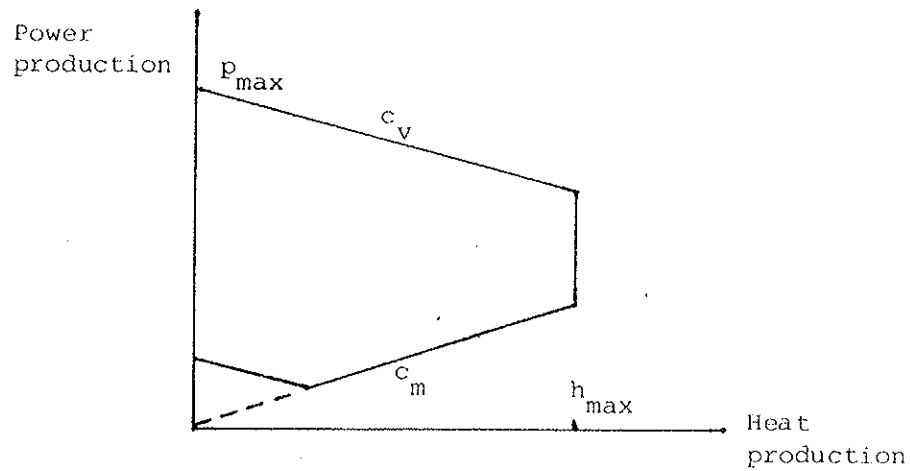


Figure 4.1. A simplified representation of a pass-out turbine.

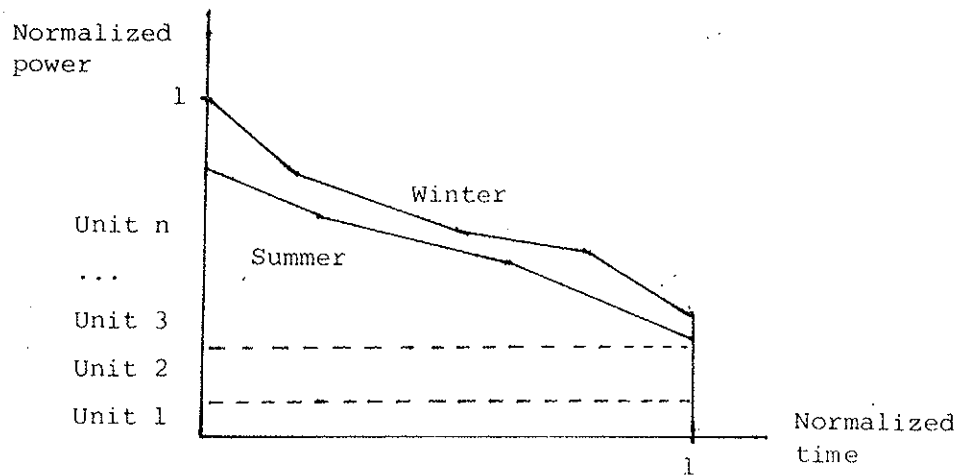


Figure 4.2. Load duration curves for the electricity generating system, winter and summer.

- the down times for maintenance and failure
- the fixed and the variable labour costs
- the fixed and the variable fuel costs
- first and last year of operation

It is possible to specify up to 100 units with different specifications, 30 of these may be new units for which first and last years are given by input parameters. There may be more than one unit with the same specifications.

4.3. The principles of simulation.

For a given year the summer and winter demands of heat and electricity must be satisfied in the most economical way taking into account the maintenance costs and unavailability. In order to obtain this the principles of load dispatch are as follows

- first the maximum power of each unit is corrected in such a way that the unavailability - all year - and maintenance - summer only - are included
- a priority list is set up according to the variable expenses - fuel and man-power. For units using the same type of fuel, the most efficient back-pressure units are given the highest priority, less efficient back-pressure units and condensing units are given lower priority. Pass-out-units are divided into a back-pressure and a condensing unit, placed at the appropriate position in the priority list. The efficiencies applied for this priority list are explained in appendix B
- heat producing units may be specified with a minimum power production in order to satisfy the heat demand by cogeneration

- the units are placed in the load duration curve as bands from the bottom according to the priority list as shown on figure 4.2. If the list is exhausted before the demand is satisfied the remaining energy may be provided by a special unit, which represents expensive peak power
- the fuel and labour costs are calculated according to the energy produced and fixed costs - labour and fuel consumption from start-ups - are added.

Thus the model calculates the following quantities

- fuel consumption of various types and the fuel costs
- maintenance costs
- heat and power produced according to fuel type or type of power station
- reserve capacity.

The present model will not simulate wind turbines due to the stochastic nature of their production. The annual production from wind turbines is calculated from a forecast of the number of these and their unit production, and the demand for power produced by thermal power stations is reduced accordingly.

Neither is hydro power included in the simulation, due to its practical non-existence in Denmark. Hydro power, however, may be included as a special power unit, or - like wind power - a forecast of hydro power production may reduce the demand for power produced by thermal power stations.

5 THE SPACE HEATING SYSTEM

5.1. Heating efficiencies.

In the energy system for space heating and domestic hot water, energy can be converted or distributed in various ways, and energy may be lost at several stages during the process of transferring primary energy into useful energy. Energy efficiencies, defined as the relation between energy output and energy input for a process, is a useful tool for analysing the energy system.

The most simple energy system for space heating consists of a stove in a room where primary energy, delivered to the house, is burned directly to provide useful energy, some energy being lost through the process.

In a central heating system two stages and two efficiencies can be defined: the furnace which produces hot water and the radiator system which distributes the hot water to the rooms.

More stages are introduced in systems of piped energy such as natural gas and district heating, or electrical heating. The structure of these systems is shown in figure 5.1.

5.2. The DES-sub-model for space heating.

Some of the stages of the heating system described in figure 5.1 are selected for calculation on a national or regional level as a part of the DES-model (Phase 5 of figure 3.1). These stages are, (see table 5.1):

- Useful Energy: energy for space heating and domestic hot water, measured at the radiator or the hot water tap, i.e. all kinds of losses in the conversion and distribution systems not included.

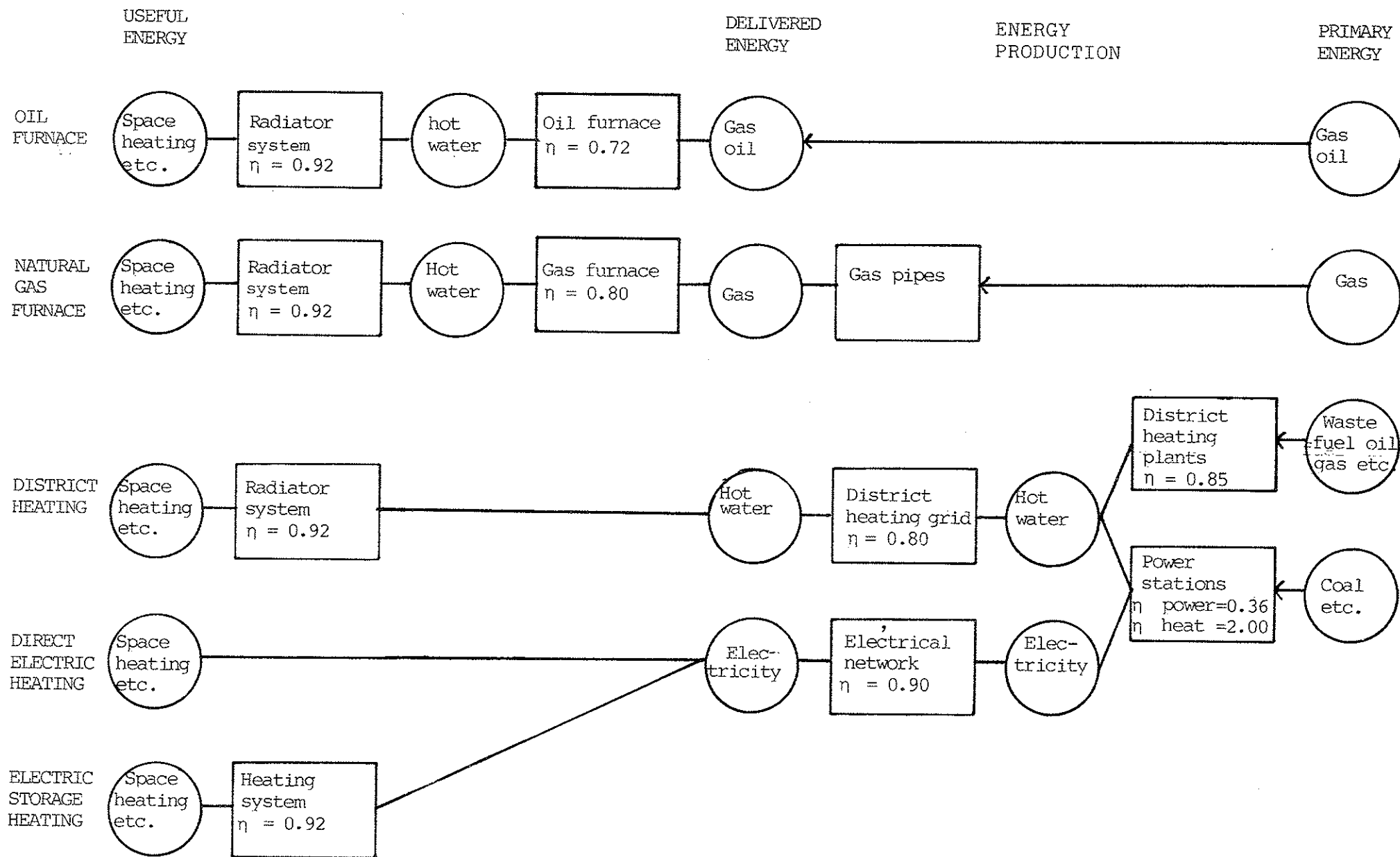


Figure 5.1. Energy system for space heating and domestic hot water in Denmark.

Table 5.1. The space heating system in Denmark 1980 and 2000.

Table 5.1. The space heating system in Denmark 1980 and 2000.

	Building area pct.	η total	Useful Energy, PJ			η local	Deliver Energy PJ	η netw.	Energy Product. PJ	η plant	Primary Energy PJ
			Resi- dential	Other Build.	Total						
Year: 1980											
Direct electricity	3	0.32	5		5	1.00	5	0.90	6	0.36	16
Electric storage heating etc.											-
District heating, CHP	15	1.47	16	8	24	0.92	26	0.80	33	2.00	16
District heating, waste + renew.	2	0.63	2	1	3	0.92	3	0.80	4	0.85	5
District heating, natural gas											
District heating, fuel oil	18	0.63	19	11	30	0.92	33	0.80	40	0.85	47
Heating centrals, fuel oil	6	0.63	6	4	10	0.92	11	0.80	14	0.85	17
Central heating, gas	2	0.74	3		3	0.74	4				4
Central heating, renewables											134
Ct. room heat, gas oil etc.	54	0.66	69	20	89	0.66	134				
Total	100	0.69	120	44	164		216				239
Building area, mill. m ²	295										0.81
Energy per unit, GJ/m ²					0.56						
Year: 2000											
Direct electricity	1	0.32	2		2	1.00	2	0.90	2	0.36	6
Electric storage heating etc.	4	0.30	6		6	0.92	7	0.90	8	0.36	23
District heating, CHP	32	1.47	37	23	60	0.92	66	0.80	82	2.00	41
District heating, waste + renew.	3	0.63	4	2	6	0.92	6	0.80	8	0.85	9
District heating, natural gas	8	0.63	9	6	15	0.92	16	0.80	20	0.85	24
District heating, fuel oil											
Heating centrals, fuel oil	9	0.63	10	7	17	0.92	19	0.80	24	0.85	28
Central heating, gas	12	0.74	20	4	24	0.74	33				33
Central heating, renewables	4	0.69	7		7	0.69	10				10
Ct. or room heat, gas oil etc.	27	0.69	43	8	51	0.69	73				73
Total	100	0.77	138	50	188		232				246
Building area, mill. m ²	395										
Energy per unit, GJ/m ²					0.48						0.62

- Delivered Energy: energy delivered to the final consumer, e.g. gas-oil delivered to the building where it is consumed, or piped energy measured by the meter at the entrance to the building.
- Energy Production: energy produced in a conversion plant (power station or district heating plant) which is sent into the transmission network.
- Primary Energy: energy consumed by a conversion plant, or non-piped energy delivered to the consumer.

Table 5.1, which shows a simplified mapping of the Danish space-heating system, is derived from a run of this sub-model. Total useful energy, delivered energy and primary energy are distributed among the various heating forms, and the total building area is distributed accordingly. The basic assumption of the sub-model is: for any particular heating form, the relation between two stages of the heating system can be expressed by an efficiency (η).

The exogenous variables for the sub-model are: total useful energy demand, energy production from CHP and waste incineration, natural gas delivery, and a few other variables such as the number of installations for renewable energy or electrical heating. The efficiencies are assumed, then the remaining variables are calculated.

The efficiencies of plants and networks may be estimated from historical data for primary energy, for energy production i.e. output from power stations and district heating plants, and for delivered energy to the final consumers. These data may be obtained from various statistical sources.

Data on useful energy and local efficiencies depend on the performance of the individual buildings, and therefore these data cannot be obtained from statistics. The assumptions were

based on a number of investigations of the energy performance of buildings. (Nørgård 1977, Christensen og Jungmark 1981). The local efficiency (η_{local}) in table 5.1 is the product of the efficiencies of the burner-boiler unit and the radiator system.

There are many definitions of the concept of primary energy. In this model refineries or treatment plants for oil, coal and gas are not included in the system, so primary energy means energy products, e.g. gas oil or fuel oil rather than crude oil. However, some renewable energy resources, especially solar and wind power cannot be quantified as fuels to which a certain heat contents and efficiencies can be assigned.

"Renewable fuels" are therefore quantified by the quantity of fossil fuel substituted as follows:

- small wind turbines, solar panels, heat pumps, straw burneres and biogas systems for single family dwellings or farm houses substitute oil burners supplied by gas oil
- waste incineration and other installations that produce hot water for district heating substitute fuel oil for district heating plants.

5.3. Space heating demand.

Space heating demand is defined as the demand for useful energy for space heating and domestic hot water in all buildings except buildings for industrial and agricultural production.

The future demand for useful energy to space heating and domestic hot water is calculated as the product of building areas and useful energy demand per m^2 .

Data on building areas by kinds and uses has been supplied from the central Building and Dwelling Register (byggnings- og boligregistret, BBR). Future building areas are found by reducing the existing building stock by a projection of demolished building area, and from forecasts of new building areas based on assumptions on the economic growth in the planning period.

Useful energy demand per m^2 in single and multi-family houses, commercial buildings, hospitals etc. built before and after 1980 has been forecasted for each of the three assumptions on economic growth and demand regulation, which were studied in EP-81 (see section 6.3).

The calculations of energy demand for space heating are done in Phase 4 of the DES-model (see fig. 3.1).

These calculations are done for the whole country, and thereafter disaggregated into 5 regions (The Natural Gas Supply Regions: Copenhagen Region, Rest of Sealand, Fyn, Southern Jutland, and Northern Jutland).

5.4. Combined heat and power, CHP.

CHP is a cornerstone of Danish heat planning. In 1980 district heating supplied by CHP covered 15 per cent of the space heating demand, and this coverage is planned to increase to about one third by the middle of the 90's.

Space-heating supplied by CHP is produced either from large power stations of 300-400 MW with pass-out condensation turbines, or from smaller units of 50-100 MW using a back-pressure turbine. Even smaller units of 15-30 MW are planned for the heat supply of medium sized towns.

The technical data of both back-pressure units and pass-out

units can vary considerably, and so can the efficiencies of heat produced by CHP.

For the EP-81 study it was assumed that heat is produced by CHP with an estimated efficiency of 2.0. This means that an output of 200 GJ hot water for the district heating grid only requires an extra input of 100 GJ of fuel to the system of power plants. The efficiency of heat produced by CHP is explained in Appendix B.

Heat production by CHP is an essential exogenous variable for the space-heating submodel. This variable is an output of the simulation of electricity and CHP-production as described in Chapter 4.

5.5. Energy savings and heat planning.

The aim of the policy of energy saving is to reduce the consumption of primary energy, especially fuels which are imported, or which cause more pollution than their alternatives.

This policy might involve the following actions:

- (1) reducing the demand for useful energy
- (2) increasing heating efficiencies of the existing system
- (3) changing the structure in favour of more efficient systems.

The reduction in energy consumption for space heating, which has been experienced in Denmark in the period 1972 to 1980, has been a combination of these three actions.

The demand for useful energy has been reduced considerably by better insulated new houses and the retrofitting of existing houses as well as behavioural changes.

Increased heating efficiencies have been obtained by more efficient oil furnaces in single family dwellings, and heating centrals for large buildings, by renewal of leaky and poorly insulated district heating pipes, and by more efficient district heating plants and power stations.

A slight increase of the total efficiency of the heating system has been obtained by an increased share of district heating supplied by CHP. On the other hand a higher proportion of electric heating has reduced the total efficiency of the heating system. At the same time, however, coal has replaced heavy oil as the most important fuel for power generation, which has reduced the fuel costs.

The 1980-figures of table 5.1 are the base for the scenarios in (EP-81). The table also shows the scenario for the year 2000 that follows the basic assumptions. According to this scenario the structure of the space heating system changes substantially. CHP-coverage increases to 32 per cent of the building area. Natural gas is introduced, and supplies 20 per cent of the building area. Renewable energy installations supply 4 per cent. Unit demand for useful energy decreases moderately, and a minor increase of efficiencies is assumed. The total efficiency increases from 0.69 to 0.77.

The existing structure of district heating in Denmark has developed through local initiative. CHP-systems producing steam or hot water for district heating have existed in the large cities for more than 50 years. These systems were expanded in the 50's and 60's, and a great number of new district heating systems were established in medium-sized and small towns. Today there are more than 400 district heating companies - owned by municipalities or co-operative bodies.

As a result of this development in the past the share of buildings in the densely populated Copenhagen Region supplied

by district heating is remarkably low, compared to the larger cities and towns, and even compared with small towns in rural regions.

Thus there is a large potential for increasing the CHP-coverage: by the expansion of the district heating grid in the Copenhagen Region, which can be connected to large power stations; and by the construction of small back-pressure units in towns with an existing grid served by a district heating plant supplied by fuel oil.

The Act on Heat Supply, which was passed in 1979, regulates the operation of collective heat supply systems, i.e. district heating and natural gas systems, and it contains a procedure for heat planning, which is an extension of the Physical Planning System that was developed during the 70's. An essential feature of the Heat Planning is the zoning of the municipalities into areas best suited for natural gas, district heating or individual heating, according to a number of criteria such as building density, proximity to the gas grid, proximity to power plants, and the existence of a district heating grid.

The sub-model for space-heating is used on both national and regional level in order to produce a description of the future heating system, and to control the consistency and credibility of forecasts and assumptions for the exogenous variables.

6 APPLICATIONS OF THE DES-MODEL

6.1. The Electrical Heating Study.

The DES-model was first used by Risø for a study of the possibilities for electrical heating in the areas of the country, which - according to the Heat Planning - would be served by neither natural gas nor CHP. This study, carried out for the Danish Association of Electricity Supply Undertakings (Danske Elværkers Forening, DEF), by Risø and the research department of DEF (DEFU), resulted in renewed interest in the use of electrical storage heating, a hitherto rare form of heating in Denmark. (DEF 1979) and a survey of the study was published in the third report from the Heat Plan Committee in 1980 (Varmeplanudvalget 1980).

6.2. The Economic Council's Study of Nuclear Power.

In June 1980 the Danish Economic Council issued a report in which the introduction of nuclear power in Denmark was discussed (Det økonomiske råd 1980). In this study a detailed examination of two alternative plans for the future development of the electricity generation system, with and without nuclear power was carried out. In the latter alternative all new power stations were assumed to be coal fired. As the parameters involved in a comparison of this kind are subject to great uncertainty, a series of calculations was made, in which quantities such as electricity demand, the rate of interest, and fuel prices were varied. In all the cases considered there was an economic advantage introducing nuclear power, although - in some of the cases - small in comparison to the total cost of power generation. The calculations were made using the DES-model for the electricity generating system corresponding to phase 1, 2 and 3 in figure 3.1.

6.3. Energy Plan 81.

The work on the new Danish Energy Plan was originally started in the spring of 1980 and the final report, entitled Energy Plan 81, was published in November 1981. The organisation of the study is described briefly below.

A number of working groups were set up to study the demand, supply, and administrative aspects of the Danish Energy System. The topics studied by these groups were:

1. Process energy
2. Space heating
3. Transport energy
4. Electricity demand
5. Imported energy
6. Danish oil and gas production
7. Technical aspects of the supply system
8. Economic analysis of the electricity generating system
9. Means of regulating demand

The Energy Plan as published consists of an assessment part, and a part outlining the Government's energy policy. The overall aim of the assessment part is to give a detailed description of the possible developments in energy demand between now and 2000, and the alternative possibilities of supplying this demand. The energy demand forecasts were carried out for three different situations: expected moderate economic growth with either unchanged or increased demand regulation, and low economic growth with existing regulation.

On the supply side, the energy plan investigated a number of alternative development plans with and without nuclear power,

with more or less utilisation of renewable energy sources and decentralised combined heat and power stations.

In order to evaluate these plans, a number of alternative supply scenarios were defined. These were combined with the three demand projections, and the DES-model was used to calculate the consequences in terms of primary energy demand and the expenditure for fuel, investment, and operation and maintenance.

6.4. Economic Analysis of the Electricity Generating System.

The purpose of this study, which was a part of the EP-81, was to update and revise earlier studies of the generating cost in a future electricity system with or without nuclear power stations (section 6.2).

The study was divided into two parts: comparisons of (1) single power stations and (2) alternative developments of the electricity generating system.

Three types of power-stations were compared, namely, a 600-MW coal-fired unit, a 900-MW light-water nuclear reactor, and a 635-MW CANDU heavy-water reactor. It was assumed that none of the units would supply CHP for district heating. Investment, fuel, operation, and maintenance costs per kWh were calculated under different assumptions with regard to prices, interest rates, etc.

Two alternative developments of the Danish electricity generating system were studied over a period of 40 years from 1980. In both cases CHP-generating units were built to fulfil the requirements of the heat plan. Further development of the generating system is based on either 600-MW coal-fired units or 900-MW nuclear units. The DES-model was used for the study.

6.5. Future applications.

The DES-Model for EP-81 contains a large number of essential data describing the Danish Energy System. These data may be utilized for more detailed studies of selected parts of the energy system, e.g. the space heating systems of various regions, or smaller variations in the areas supplied by CHP.

Furthermore the DES-model might be utilized as a data-base for energy related data on national and regional level, which can be updated by new statistics and new studies.

APPENDIX A.

An Example of the DES-Model.

This appendix contains a description of the most important concepts of the DES-program followed by the printout from a run of a simplified partial model describing the space-heating system.

A.1. Basic concepts of the DES-program.

Account is a variable described by a number and a text. Each account is represented by a record on a system-file, the record containing a number of words corresponding to the calculation period (max. 40 years) plus some auxiliary quantities. An account is declared by datatype NAVN (see below). The contents of an account can be specified in various ways, see datatypes DATA, KONT, REGN and FUNK, below

Datatypes. Data are system orders, input parameters and other quantities which are necessary to define and run a model. The following datatypes are used in the DES-program.

NAVN (name) followed by account numbers and an informative text declares the accounts at the system-file by reserving a record for each account

FASE (phase) is a system order defining and labeling a model phase, which is a set of data of type DATA, KONT, REGN, FUNK and NOTE that will be treated together as a logical unit,

DATA is an order by means of which the values for an account may be specified for every year

KONT is used if the values for an account are specified by constant, or a base value together with a linear or exponential development in certain time intervals,

REGN specifies that the values for an account are given by an assignment, which is an arithmetic expression of the form $Y=A+B*C-D/E$ (the letters representing account numbers, the operators are FORTRAN-operators). The calculations are done strictly from left to right. There is, however, at possibility for two parentheses structures:

& : $Y=A*B+(C*E)$ or $Y=A*B+(C/E)$ is written $Y=A*B\&C*E$, where $C*E$ (or C/E) is calculated and added to $A*B$

! : $Y=A*B-(C*E)$ is written $Y=A*B!C*E$ where $C*E$ is calculated and subtracted from $A*B$

The variables may be further specified by a suffix

G (gammel=old) states that last year's value is to be used

S (start) states that the start year's value is to be used

T (tal=number) as distinct from account number - is used for a constant.

Other arithmetic expressions may be defined as functions.

FUNK is an order which demands that the values of one or more variables are calculated using a FORTRAN-subroutine which specifies the relationship between several variables.

NOTE comments may be included in the input data using this order.

The statements in a phase are treated successively, but an account must be assigned before it can be used. A phase can be calculated and recalculated independently of other phases as long as the above is fulfilled. Errors will often arise from wrong formatting or missing definition or assignment of an account.

PROD is an order which activates an input procedure of data for power units and of duration curves. Simulation of electricity production is done by calling a subroutine using FUNK "PROD"

FORM specification which states how the results are to be printed. The printout is arranged in logical pages, each with a given heading. A "page" need not correspond to a page of paper.

SLET order which purges the system completely and reserves a number of positions on the account file, corresponding to the given period. In addition a main heading is read which is printed in the top left side of each page.

PARA order which states the period over which the model is to be run. In addition, a heading and a reporting period is specified. The specified period must be covered by the period in SLET.

BRGN order which states that the following phases must be calculated in the period which is specified under PARA. If there are more phases after BRGN they are all executed for a given year, before the next year is calculated. Errors will typically be due to attempts to use accounts which are not assigned for that year.

LIST produces printouts when the desired page is specified. With this order one can in addition print auxiliary quantities, and make graphs, LIST DOKU XXXX will give a very detailed printout of FASE XXXX with statements and actual contents of accounts.

STOP order which causes stop of calculations. The completed orders are saved on permanent system files so that restart is possible.

A.2. Further capabilities: Model with two or more systems.

If more than one set of system files have been created, they can be compared or linked together, using the following orders.

FLYT (move) moves the contents of an account from a specified system to an arbitrary account in the running system.

SUMM adds the contents of accounts with identical numbers from two specified systems. The results are stored in the same account numbers in the running system.

DIFF subtracts the contents of accounts in one system from the contents of the same account in another system. The results are stored in the same account in the running system.

A.3. Simple example of data to a DES-model.

Below is shown a small example of a run of the DES-model. The documentary output and results of two input-files are shown. The first file contains the orders that define the model. The second file contains the orders that run the calculations and write the results.

The example constructs a simplified version of Danish space heating system, which is described in Chapter 5 of this report.

The example is self-explanatory as comments are given through NOTES . The documentary output is merely an editing of the input-files, which are not shown.

The following copy of the output shows how the data has been processed. It can be seen how the headings are reproduced, and that the program itself adds date, time and an explaining text. The text "NR. 2" at the top middle of each page refers to the number of runs of the running system since being established, i.e. since the order SLET .

```

*****
*                               *
*   D E S   *   VERSION DIS/MAINI AF 18 MAR 82   *
*                               *
*****

```

CORE ANVENDES TIL AARSVARIABLE

SLET

SAMLE DATA SLETTES. NYT SYSTEM GENERERES MED NAVNET SPACE HEATING SYSTEM 01OKT82
PERIODE FRA 1979 TIL 2019

PARA

SPACE HEATING SYSTEM 01OKT82 MODEL DEFINITIONS 01OKT82

NR 1 01.-10.-1982-14: 9 PARAMETRE

BEREGNINGSPERIODE FRA 1980 TIL 2000
RAPPORTPERIODER FRA 1980 TIL 1988
NOTE

SLET HAS THE EFFECT THAT AN EXISTING RUNNING SYSTEM - FILES 1/2 - IS
---- REMOVED, AND A NEW SYSTEM IS CREATED. THIS SYSTEM IS IDENTIFIED
BY THE TEXT, WHICH WILL BE WRITTEN AT THE TOP LEFT OF EACH OUTPUT
PAGE. ACCOUNTS MAY BE CALCULATED FOR THE YEARS 1980-2019, 1979
BEING THE 'START'-YEAR.
PARA HAS THE EFFECT THAT CALCULATIONS ARE MADE FOR THE PERIOD 1980-
---- 2000. LATER RUNS MAY START FOR YEAR 2001. THE SPECIFIED TEXT
WILL APPEAR IN THE MIDDLE TOP ON EACH PAGE UNTIL OVERWRITTEN BY
A NEW 'PARA'. THE PERIOD 1980-1988 STATES THE YEARS FOR WHICH
RESULTS SHALL BE PRINTED OUT.
NOTE HAS THE EFFECT THAT THE FOLLOWING TEXT - I.E. ALSO THIS TEXT -
---- IS COPIED EXACTLY FROM INPUT TO OUTPUT WITHOUT ANY OTHER ACTION
UNTIL A 'SACRED' WORD IS MET, E.G. 'NAVN'.
OBS! COLUMNS 1-4 IS RESERVED FOR 'SACRED' WORD, WHILE COLUMNS 5-8 AS
---- A RULE CONTAIN ACCOUNT NUMBERS OR NAME OF PHASES. THE REST OF
THE LINE IS FORMATTED ACCORDING TO USE.

NAVN

SPACE HEATING SYSTEM 010KT82 MODEL DEFINITIONS 010KT82
KONTONR KONTOBETEGNELSE OPE. KOMMENTARER

NR 1 01.-10.-1982-14: 9

KONTI DEFINERES

```

49 EFFICIENCY RADIATOR SYSTEM
50 EFFICIENCY OIL FURNACE
52 EFFICIENCY DIST.HEAT.PLANT
53 EFFICIENCY DIST.HEAT.GRID
55 EFFICIENCY GAS FURNACE
60 EFFICIENCY ELECTRICAL GRID
70 EFFICIENCY POWER STATIONS
71 EFFICIENCY COGENERAT. HEAT
1309 TOTAL EFFICIENCY
2300 USEFUL ENERGY PJ
2307 DELIVERED ENERGY PJ
2309 PRIMARY ENERGY PJ
2317 ELECTRICITY DELIVERED PJ
2318 ELECTRICITY PRODUCED PJ
2319 ELECTRICITY PRIM.ENERGY PJ
2320 DIRECT ELEC.HEAT USEFUL PJ
2330 EL. STORAGE HEAT USEFUL PJ
2337 EL. STORAGE HEAT DELIV. PJ
2400 DIST.HEAT. TOTAL USEFUL PJ
2407 DIST.HEAT. TOTAL DELIV. PJ
2408 DIST.HEAT. TOTAL PRODUC. PJ
2410 DIST.HEAT. CHP USEFUL PJ
2417 DIST.HEAT. CHP DELIV. PJ
2418 DIST.HEAT. CHP PRODUC. PJ
2419 DIST.HEAT. CHP PRIMAR. PJ
2490 DIST.HEAT. OTHER USEFUL PJ
2497 DIST.HEAT. OTHER DELIV. PJ
2498 DIST.HEAT. OTHER PRODUC. PJ
2499 DIST.HEAT. OTHER PRIMAR. PJ
2520 INDIV.HEAT. GAS USEFUL PJ
2529 INDIV.HEAT. GAS PRIMAR. PJ
2590 INDIV.HEAT. OTHER USEFUL PJ
2599 INDIV.HEAT. OTHER PRIMAR. PJ

```

ANTAL AKTIVE KONTI: 33, MAXIMALT: 777

NOTE

NAVN HAS THE EFFECT THAT SPACE IS RESERVED ON THE SYSTEM FILES FOR
--- THE ACCOUNTS, WHICH ARE DEFINED BY A NUMBER (0001-3000) AND A
TEXT.

FASE

HEAT

NOTE

====

FASE HAS THE EFFECT THAT WHAT COMES AFTER IS STORED MARKED 'HEAT', SO
 ---- THAT WHEN THIS PHASE IS CALCULATED THE MARKED ORDERS WILL BE
 EXECUTED.

THE MODEL-PHASE 'HEAT' CONTAINS THE ARITHMIC EXPRESSIONS FOR THE
 SPACE HEATING SYSTEM.

THE FOLLOWING ACCOUNTS ARE CALCULATED IN OTHER MODEL-PHASES AND THUS
 EXOGENOUS FOR THIS PARTIAL MODEL: 2300, 2320, 2330, 2400, 2418,
 AND 2520

PRIMARY ENERGY REQUIREMENT IS CALCULATED FROM THESE ACCOUNTS USING
 THE EFFICIENCIES, WHICH ARE SPECIFIED IN MODEL-PHASE 'EFFI'.

REGN

====

KONTONR	KONTOBETEGNELSE	REGNEUDTRYK	(OPERAND - SUFFIX - OPERATOR)
2317	ELECTRICITY DELIVERED PJ =	2320 / 2330	S*0 / S*0 S*0-----S*0-----S*0
2318	ELECTRICITY PRODUCED PJ =	2317 / 0069	
2319	ELECTRICITY PRIM.ENERGY PJ =	2318 / 0070	
2407	DIST.HEAT. TOTAL DELIV. PJ =	2400 / 0049	
2408	DIST.HEAT. TOTAL PRODUC. PJ =	2407 / 0053	
2498	DIST.HEAT. OTHER PRODUC. PJ =	2408 / 2418	
2419	DIST.HEAT. CHP PRIMAR. PJ =	2418 / 0071	
2499	DIST.HEAT. OTHER PRIMAR. PJ =	2498 / 0052	
2529	INDIV.HEAT. GAS PRIMAR. PJ =	2520 / 0049	
2590	INDIV.HEAT. OTHER USEFUL PJ =	2300 - 2320	0055 - 2400 - 2520
2599	INDIV.HEAT. OTHER PRIMAR. PJ =	2590 / 0049	0050
2309	PRIMARY ENERGY PJ =	2319 + 2419	2499 + 2529 + 2599
1309	TOTAL EFFICIENCY PJ =	2300 / 2309	

NOTE

====

REGN SPECIFIES THE ACTUAL ASSIGNMENTS GIVEN BY ARITHMIC EXPRESSIONS,
 ---- E.G. THE ASSIGNMENT FOR ACCOUNT 2317, ELECTRICAL HEATING DELIV-
 ERED, MEANS THAT USEFUL ELECTRICAL STORAGE HEATING DIVIDED BY
 THE EFFICIENCY OF THE RADIATOR SYSTEM IS ADDED TO USEFUL DIRECT
 ELECTRICAL HEATING (THE EFFICIENCY OF THE RADIATOR SYSTEM FOR THIS
 FORM OF HEATING BEING 1.0)

THEN THE DISTRIBUTION OF DELIVERED ENERGY AND USEFUL ENERGY BY
 HEATING FORM IS CALCULATED.

REGN

====

KONTONR	KONTOBETEGNELSE	REGNEUDTRYK	(OPERAND - SUFFIX - OPERATOR)
2337	EL. STORAGE HEAT DELIV. PJ =	2330 / 0049	S*0 / S*0 S*0-----S*0-----S*0
2307	DELIVERED ENERGY PJ =	2320 + 2337	2407 + 2529 + 2599
2417	DIST.HEAT. CHP DELIV. PJ =	2413 * 0053	
2497	DIST.HEAT. OTHER DELIV. PJ =	2498 * 0053	
2410	DIST.HEAT. CHP USEFUL PJ =	2417 * 0049	
2490	DIST.HEAT. OTHER USEFUL PJ =	2497 * 0049	

SPACE HEATING SYSTEM 010KT82 MODEL DEFINITIONS 010KT82

NR 1 01.-10.-1982-14: 9

NOTE

====

SPECIFICATION OF EFFICIENCIES

KONT

====

KONTNR	KONTOBETEGNELSE	BASISVAERDI	OPE1	OPERAND	FRA-TIL OPE2-KONTO
		S			S
49	EFFICIENCY RADIATOR SYSTEM	0.92			
50	EFFICIENCY OIL FURNACE	0.72	LINE	0.002	1980 1994
		0.75			1995
52	EFFICIENCY DIST.HEAT.PLANT	0.85			
53	EFFICIENCY DIST.HEAT.GRID	0.80			
55	EFFICIENCY GAS FURNACE	0.80			
69	EFFICIENCY ELECTRICAL GRID	0.90			
70	EFFICIENCY POWER STATIONS	0.36			
71	EFFICIENCY COGENERAT. HEAT	2.00			

NOTE

====

KONT SPECIFIES THE VALUE OF E.G. ACCOUNT 0050 TO 0.72 IN 1980
---- INCREASING LINIARLY WITH THE INCREMENT OF 0.002 UNTIL 1994.
FROM 1995 THE VALUE IS 0.75.

FORM

SPACE HEATING SYSTEM 010KT82 MODEL DEFINITIONS 010KT82
 KONTORR OPE1 OPE2 TEKST

NR 1 01.-10.-1982-14: 9'

	SIDE TEXT	HEAT TV	SPACE HEATING SYSTEM
	MAAR		
	LINE		
	BLAN		
2320	H		
2330	H		
2410	H		
2490	H		
2520	H		
2590	H		
	BLAN		
2300	H		
	BLAN		
2317	H		
2417	H		
2497	H		
2529	H		
2599	H		
	BLAN		
2307	H		
	BLAN		
2318	H		
2418	H		
2498	H		
	BLAN		
2319	H		
2419	H		
2499	H		
2529	H		
2599	H		
	BLAN		
2309	H		
	BLAN		
1309			
	BLAN		
	BLAN		
49			
	BLAN		
69			
70			
	BLAN		
53			
71			
52			
	BLAN		
55			
50			
	LINE		

NOTE

FORM SPECIFIES THE PRINTED FORMAT FOR THE RESULTS.
 ---- THE OUTPUT IS DIVIDED INTO PAGES USING THE ORDER:
 SIDE WHICH STATES THAT THE FOLLOWING SPECIFICATION (UNTIL EITHER NEW
 ---- 'SIDE' OR OTHER ORDER IS MET) BE OUTPUT TOGETHER.
 TEXT PRODUCES A HEADING THE POSITION OF WHICH IS SPECIFIED BY
 ---- 'TV'(LEFT), 'TH'(RIGHT) OR 'MIDT'(CENTRE);
 THE CONTENTS ARE SPECIFIED BY SUBSEQUENT TEXT.
 LINI PRODUCES A LINE ACROSS THE PAGE.

 BLAN PRODUCES A BLANK LINE

 AR PRINTS THE RUNNING YEAR AT THE TOP OF THE PAGE

 MAAR PRINTS SPECIFIED SINGLE OR INTERVALS OF YEARS (MAX 10 YEAR)
 ---- ON THE SAME PAGE
 ACCOUNT NUMBERS TO BE PRINTED MAY BE FOLLOWED BY A NUMBER STATING
 ---- THE NUMBER OF DECIMALS; BY DEFAULT THREE
 ---- DECIMALS ARE OBTAINED. 2, 1, H (INTEGER) CAN ALSO BE USED.

STOP

```

*****
* D E S *   VERSION DIS/MAINI AF 18 MAR 82   *
*
*****

```

CORE ANVENDES TIL AARSVARIABLE

```

SPACE HEATING SYSTEM 010KT82  MODEL DEFINITIONS 010KT82          NR 1  01.-10.-1982-14: 9  SIDSTE KQRS
PARA
****
SPACE HEATING SYSTEM 010KT82  SCENARIO XX 010KT82              NR 2  01.-10.-1982-14: 9  PARAMETRE
BEREGNINGSPERIODE FRA 1980 TIL 2000
RAPPORTPERIODER   FRA 1980 TIL 1982   FRA 1985 TIL 1985   FRA 1990 TIL 1990   FRA 1995 TIL 1995   FRA 2000 T

```

NOTE

THIS INPUT-FILE DOES NOT BEGIN WITH A 'SLET', SO A SET OF SYSTEM FILES
- FILES 1/2 - MUST ALREADY EXIST.

PARA AS THIS FILE CONTAINS EXECUTION STATEMENTS THE NUMBER OF YEARS TO
---- BE CALCULATED (1980-2000) IS ESSENTIAL FOR THE TIME OF COMPUTA-
TION. THE TEXT, WHICH IS PRINTED AT EACH OUTPUT-PAGE - IS USED FOR
IDENTIFICATION OF THE PARTICULAR SCENARIO DEFINED BY THIS FILE.
THE PERIODS STATED IN THE SECOND LINE WILL BE PRINTED ON THE SAME
PAGE, WHEN THE ORDER 'MAAR' IS APPLIED UNDER THE FORMAT SPECIFI-
CATION, OTHERWISE - BY THE ORDER 'AR' EACH PERIOD WILL BE PRINTED
ON ONE PAGE.

FASE

NEWD

SPACE HEATING SYSTEM 010KT82 SCENARIO XX 010KT82

NR 2 01.-10.-1982-14: 9 FASE NEWD

NOTE

====

SPECIFICATION OF VARIABLES, WHICH ARE PARTICULAR FOR THIS SCENARIO.

DATA

====

KONTONR	KONTORTEGNEELSE	DATA FOR HVERT AAR						
		1979-86-93 2000- 7-14	80-87-94 1- 8-15	81-88-95 2- 9-16	82-89-96 3-10-17	83-90-97 4-11-18	84-91-98 5-12-19	85-92-99 6-13
71	EFFICIENCY COGENERAT. HEAT	2.00	2.00	2.00	2.00	2.00	2.00	1.95
		1.95	1.95	1.95	1.95	1.90	1.85	1.85
		1.85	1.85	1.80	1.80	1.80	1.80	1.80
		1.80	0.00	0.00	0.00	0.00	0.00	0.00

NOTE

====

DATA SPECIFIES YEARLY VALUES FOR ACCOUNT 0071.
 THE FIRST VALUE IS ALWAYS FOR THE START-YEAR HENCE
 A CHANGE OF THE PERIOD DEFINED BY 'SLET' MEANS THAT THESE NUMBERS
 REFER TO OTHER YEARS THAN ABOVE, UNLESS THE START-YEARS ARE ID-
 ENTICAL. UNSPECIFIED YEARLY VALUES ARE SET TO ZERO.
 THE VALUES FOR THIS ACCOUNT THAT WERE SPECIFIED IN PHASE 'EFFI'
 ARE NOW REPLACED BY THIS NEW SPECIFICATION.

THE CHANGES OF THE EFFICIENCY OF CHP MAY BE DUE TO A JUDGEMENT
 BASED ON A STUDY USING THE SIMULATION MODEL FOR THE ELECTRICITY
 GENERATING SYSTEM, WHICH IS DESCRIBED IN APPENDIX B OF THIS RE-
 PORT. AS NEW AND MORE EFFICIENT POWER STATIONS ARE TAKEN INTO
 OPERATION, THE EFFICIENCY OF THE MARGINAL CONDENSING UNIT WILL
 INCREASE, AND THEREFORE THE EFFICIENCY OF COGENERATED HEAT WILL
 DECREASE TO 1.80.

SPACE HEATING SYSTEM 010KT82 SCENARIO XX 010KT82

NR 2 01.-10.-1982-14: 9 FASE NEWD

FLYT

FLYTNING AF KONTI FRA SYSTEM: EP-81 RUMOPVARMNING 30MAR82 SPACE HEATING DATA 17SEP82
TIL SYSTEM: SPACE HEATING SYSTEM 010KT82 SCENARIO XX 010KT82

NR 13 24.-09.-1982-11:13
NR 2 01.-10.-1982-14: 9

KONTO 162 - 162 FLYTTES FRA FIL11 TIL KONTO 70 - 70 PAA FIL1
KONTO 162 RES.VIRKNINGSGR.TERMISK EL FLYTTET TIL KONTO 70 EFFICIENCY POWER STATIONS
KONTO 2300 - 2300 FLYTTES FRA FIL11 TIL KONTO 0 - 0 PAA FIL1
KONTO 2300 NETTOVARMEFORBRUG PJ FLYTTET TIL KONTO 2300 USEFUL ENERGY PJ
KONTO 2320 - 2320 FLYTTES FRA FIL11 TIL KONTO 0 - 0 PAA FIL1
KONTO 2320 DIREKTE ELVARME NT.VARM.PJ FLYTTET TIL KONTO 2320 DIRECT ELEC.HEAT USEFUL PJ
KONTO 2330 - 2330 FLYTTES FRA FIL11 TIL KONTO 0 - 0 PAA FIL1
KONTO 2330 AKK. ELVARME NT.VARM.PJ FLYTTET TIL KONTO 2330 EL. STORAGE HEAT USEFUL PJ
KONTO 2400 - 2400 FLYTTES FRA FIL11 TIL KONTO 0 - 0 PAA FIL1
KONTO 2400 FJERNVARME IALT NT.VARM.PJ FLYTTET TIL KONTO 2400 DIST.HEAT. TOTAL USEFUL PJ
KONTO 2418 - 2418 FLYTTES FRA FIL11 TIL KONTO 0 - 0 PAA FIL1
KONTO 2418 KRAFTVARME AS VERK PJ FLYTTET TIL KONTO 2418 DIST.HEAT. CHP PRODUC.PJ
KONTO 2520 - 2520 FLYTTES FRA FIL11 TIL KONTO 0 - 0 PAA FIL1
KONTO 2520 GASFYR NT.VARM.PJ FLYTTET TIL KONTO 2520 INDIV.HEAT. GAS USEFUL PJ

NOTE

FLYT (MOVE) HAS THE EFFECT THAT THE VALUES OF AN ACCOUNT IN ANOTHER
---- SYSTEM 11/12 - ARE TRANSFERRED TO THE RUNNING SYSTEM - FILES
- FILES 1/2 - TO THE ACCOUNT WITH THE SAME NUMBER, OR IF
TIL (TO) IS APPLIED TO AN ARBITRARY ACCOUNT

EXISTING VALUES FOR THESE ACCOUNTS ARE REPLACED BY THE NEW ONES.

BRGN

NEWD
EFFI
HEAT

NOTE

BRGN HAS THE EFFECT THAT THE MODEL-PHASES 'NEWD', 'EFFI' AND 'HEAT'
---- ARE CALCULATED IN THIS ORDER.
AS THE PHASES 'NEWD' AND 'EFFI' ONLY CONTAIN DATA SPECIFIED BY
THE 'DATA' AND 'KONT' ORDERS, WHICH ARE CALCULATED WHEN DEFINED,
NO CALCULATION OF THESE PHASES WILL TAKE PLACE. THE MODEL-PHASE
'HEAT', HOWEVER, CONTAINS DATA SPECIFIED BY THE ORDER 'REGN',
WHICH ARE CALCULATED BY THE EXECUTION ORDER 'BRGN'.

LIST PRODUCES OUTPUT OF TABLES, GRAPHS,
---- DOCUMENTATION ETC. AS SPECIFIED BY THE OPERATORS:
SIDE HEAT (TOP RIGHT ON OUTPUT PAGE) ORDERS PRINTOUT OF PAGE HEAT AS
---- DEFINED ABOVE.

LIST

SPACE HEATING SYSTEM 010KT82				SCENARIO XX 010KT82		NR 2 01.-10.-1982-14: 9		SIDE HEAT		
SPACE	HEATING SYSTEM			1980	1981	1982	1985	1990	1995	2000
2320	DIRECT ELEC.HEAT	USEFUL PJ		5	5	5	5	3	2	2
2330	EL. STORAGE HEAT	USEFUL PJ		0	0	0	1	4	6	7
2410	DIST.HEAT. CHP	USEFUL PJ		24	26	28	41	53	59	60
2490	DIST.HEAT. OTHER	USEFUL PJ		43	40	40	31	28	35	38
2520	INDIV.HEAT. GAS	USEFUL PJ		3	3	3	7	21	24	24
2590	INDIV.HEAT.OTHER	USEFUL PJ		89	83	81	72	58	52	57
2300	USEFUL ENERGY	PJ		164	158	158	157	167	177	188
2317	ELECTRICITY DELIVERED	PJ		5	5	5	6	7	8	9
2417	DIST.HEAT. CHP	DELIV. PJ		26	29	31	45	58	64	66
2497	DIST.HEAT. OTHER	DELIV. PJ		47	44	43	34	31	38	42
2529	INDIV.HEAT. GAS	PRIMAR.PJ		4	4	4	10	29	33	33
2599	INDIV.HEAT.OTHER	PRIMAR.PJ		134	126	121	107	85	75	83
2307	DELIVERED ENERGY	PJ		216	207	205	201	209	218	232
2318	ELECTRICITY PRODUCED	PJ		6	6	6	7	8	9	10
2418	DIST.HEAT. CHP	PRODUC.PJ		33	36	39	56	72	80	82
2498	DIST.HEAT. OTHER	PRODUC.PJ		38	54	54	42	38	47	52
2319	ELECTRICITY PRIM.ENERGY	PJ		16	16	16	18	22	24	27
2419	DIST.HEAT. CHP	PRIMAR.PJ		16	18	19	29	38	44	45
2499	DIST.HEAT. OTHER	PRIMAR.PJ		69	64	64	49	45	56	61
2529	INDIV.HEAT. GAS	PRIMAR.PJ		4	4	4	10	29	33	33
2599	INDIV.HEAT.OTHER	PRIMAR.PJ		134	126	121	107	85	75	83
2309	PRIMARY ENERGY	PJ		239	228	225	214	218	232	249
1309	TOTAL EFFICIENCY			0.636	0.695	0.700	0.736	0.765	0.765	0.757
49	EFFICIENCY RADIATOR SYSTEM			0.920	0.920	0.920	0.920	0.920	0.920	0.920
69	EFFICIENCY ELECTRICAL GRID			0.900	0.900	0.900	0.900	0.900	0.900	0.900
70	EFFICIENCY POWER STATIONS			0.363	0.371	0.363	0.361	0.366	0.381	0.384
53	EFFICIENCY DIST.HEAT.GRID			0.800	0.800	0.800	0.800	0.800	0.800	0.800
71	EFFICIENCY COGENERAT. HEAT			2.000	2.000	2.000	1.950	1.900	1.800	1.800
52	EFFICIENCY DIST.HEAT.PLANT			0.850	0.850	0.850	0.850	0.850	0.850	0.850
55	EFFICIENCY GAS FURNACE			0.800	0.800	0.800	0.800	0.800	0.800	0.800
50	EFFICIENCY OIL FURNACE			0.720	0.722	0.724	0.730	0.740	0.750	0.750

APPENDIX B.

Efficiencies of Cogenerated Heat and Power, CHP.

By separate production of power and heat, the production per unit of fuel may be either 0.3-0.4 units of power or 0.8-0.9 units of heat, or any combination of these. In figure 1 power production by a condensing turbine is represented by OP, and heat production in a district heating plant by OH. The line PH shows the combinations of power and heat produced by a unit of fuel given the efficiencies of the conversion plants.

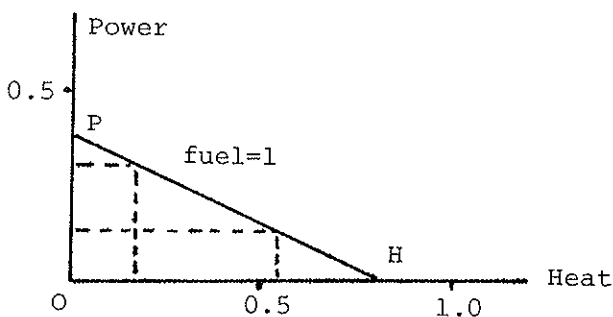


Figure 1. Power and heat produced by a unit of fuel using separate production only.

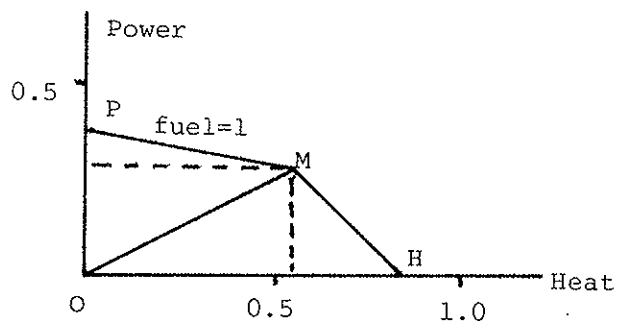


Figure 2. Power and heat produced by a unit of fuel using separate production or cogeneration by a back-pressure turbine.

By cogeneration the compound efficiency of power plus heat may reach 0.7-0.9. In figure 2 cogeneration by a back-pressure turbine is represented by the line OM. The slope of this line, c_m , which is power production per unit of heat produced by the turbine may be up to 0.6, the actual figure

being determined by the technical lay-out of the turbine. The line PMH shows the combinations of power and heat produced by a unit of fuel given the efficiencies of the three types of conversion plants.

B 1. The energy system.

The energy system to be studied may consist of these three types of conversion plants

- condensing turbines, producing power
- back-pressure turbines, producing power and heat, and
- district heating plants, producing heat

All power producing plants are interconnected within an electricity generating system, e.g. Denmark east or west of the Great Belt. Within an area of an electrical generating system, there may be several heat regions. A heat region is a town or conurbation with a district heating grid supplied by cogeneration.

The relationship between the marginal power demand (p) the marginal heat demand (h) and the marginal fuel requirement (f) can be described with the following parameters:

- η_p the efficiency, i.e. power per unit fuel, of the marginal condensing turbine in the electrical generating system
- η_m the efficiency, i.e. power plus heat per unit fuel, of the marginal back-pressure turbine in the heat region
- c_m power per unit heat produced by this turbine
- η_h the efficiency, i.e. heat per unit fuel, of usual district heating plants.

The efficiencies of cogeneration,

η_p^{CHP} the fuel required for the marginal production of power by a back-pressure turbine, given the demand for heat in the heat region supplied by this turbine,

η_h^{CHP} the fuel required for the marginal production of heat by a back-pressure turbine, given the total demand for power in the electricity generating system,

are derived from the following expressions for marginal fuel requirement for production by the three types of conversion plants, see figure 2:

$$OP \text{ (condensing turbine)} \quad f = \frac{p}{\eta_p} \quad \text{for } h=0 \quad (1)$$

$$OM \text{ (back-pressure turbine)} \quad f = \frac{p+h}{\eta_m} = \frac{(c_m+1)p}{c_m \eta_m} \quad \text{as } h = \frac{p}{c_m} \quad (2)$$

$$OH \text{ (district heating plant)} \quad f = \frac{h}{\eta_h} \quad \text{for } p=0 \quad (3)$$

The efficiencies also express economic efficiency, if all fuel prices are the same. The model can be modified to include different fuels at different prices.

The model may also be modified to include pass-out turbines allowing both condensing and back-pressure production.

B. 2. The efficiency of cogenerated power.

Let the demand for heat (h) be given for the heat region supplied by the back-pressure turbine considered. This heat can be produced either by the back-pressure turbine within its limit of capacity (h_1) or by district heating plants with no virtual limit of capacity (h_2):

$$h = h_1 + h_2 \quad (4)$$

Inserting h_1 and h_2 for h in (2) and (3) and adding we have

$$f = \frac{p+h_1}{\eta_m} + \frac{h_2}{\eta_h} = \frac{(c_m+1)p}{c_m \eta_m} + \frac{h - \frac{p}{c_m}}{\eta_h} \quad (5)$$

or

$$p = \frac{c_m \eta_m f - \frac{\eta_m}{\eta_h} c_m h}{c_m + 1 - \frac{\eta_m}{\eta_h}} \quad (6)$$

and the efficiency of cogenerated power is found as the partial derivative of this function with respect to f given h

$$\eta_p^{CHP} = \left. \frac{\delta p}{\delta f} \right|_h = \frac{c_m \eta_m}{c_m + 1 - \frac{\eta_m}{\eta_h}} \quad (7)$$

For $\eta_m \approx \eta_h$ we have from (6) and (7)

$$p \approx \eta_m f - h \quad (6a)$$

and

$$\eta_p^{CHP} = \left. \frac{\delta p}{\delta f} \right|_h \approx \eta_m \quad (7a)$$

The efficiencies, η_h , for district heating plants show little variation, and may thus be treated as a constant, making η_p^{CHP} a function of c_m and η_m . There is virtually no capacity limit for heat production in any heat region, as large capacity reserves are usual, and new plants may be constructed at relatively low investment costs.

The efficiencies, η_m , for back-pressure turbines, however, may vary considerably, as well as the c_m -value, depending on the technical layout and the vintage of the turbine.

Futhermore investment costs are high, so there is a virtual capacity limit for CHP in each heat region. The efficiencies of modern back-pressure turbines - and pass-out turbines producing back-pressure - are very close to the efficiency of district heating plants, giving the simplified expressions (6a) and (7a).

The electricity generating system consists of many interconnected units with different specifications. By economic dispatching the turbines are taken into operation according to their economic efficiencies. Base-load is produced by CHP-turbines and the most efficient condensing turbines. Older and less efficient turbines must be taken into operation at peak load. Thus, the back-pressure turbine considered will be allowed to produce power within its limit of capacity and within the heat demand in its heat region, as long as

$$\eta_p^{CHP} > \eta_p \quad (8)$$

and the prices of fuel are the same for these two power-stations.

B. 3. The efficiency of cogenerated heat.

Let the demand for power (p) be given for the whole electricity generating system. This demand can be produced either by condensing turbines (p_1) or by the back-pressure in the heat region considered (p_2) within its limit of capacity:

$$p = p_1 + p_2 \quad (9)$$

Inserting p_1 and p_2 for p (1) and (2), we have

$$f = \frac{p_1}{\eta_p} + \frac{p_2 + h}{\eta_m} = \frac{p - c_m h}{\eta_p} + \frac{c_m h + h}{\eta_m} \quad (10)$$

or

$$h = \frac{\eta_p f - p}{c_v} \quad (11)$$

and the efficiency of cogenerated heat is found as the partial derivative of this function with respect to f , given p

$$\eta_h^{CHP} = \left. \frac{\delta h}{\delta f} \right|_p = \frac{\eta_p}{c_v} \quad (12)$$

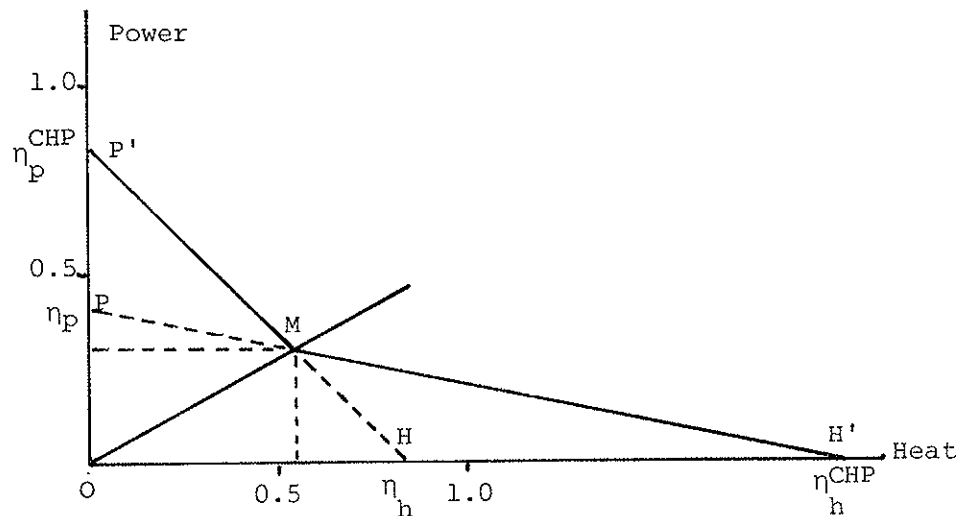
where

$$c_v = \frac{\eta_p}{\eta_m} - \left(1 - \frac{\eta_p}{\eta_m} \right) c_m \quad (13)$$

is the slope of the line PM in figure 2.

Like in figure 2, the line OM in figure 3 represents the combinations of power and heat, which can be produced from a unit of fuel in a back-pressure turbine. The line P'MH' in figure 3 shows the combinations of power and heat produced by the marginal unit of fuel in the system of interconnected conversion plants, where separate production may be displaced by combined production.

Figure 3. Power and heat produced by the marginal unit of fuel, within the capacity limit of cogeneration of a back-pressure turbine in a system of interconnected conversion plants.



The parameters η_m and c_m are technical specifications for the back-pressure turbine considered. The parameter η_p , however, is the efficiency of the marginal condensing turbine in the whole electricity generating system. If the generating system consists of turbines with a wide range of

efficiencies, η_p may vary considerably depending on the load of the total system, and thus the parameters c_v and η_p^{CHP} for the heat region considered can vary considerably over time.

B.4. Pass-out turbines.

A pass-out turbine allows both condensing and back-pressure production, and any combination of these within certain limits of variation.

If condensing production by a pass-out is non-marginal, i.e. more efficient than the marginal condensing turbine in the electricity generating system, the pass-out turbine will be allowed to produce at full capacity. When back-pressure production is increased by one unit of fuel, the non-marginal condensing production by the pass-out turbine must be reduced and displaced by production on the marginal condensing turbine, thus reducing the marginal output of power from the increase in combined production.

The effects of this reduction are shown graphically in figure 4. The corrected expressions for the efficiencies of cogeneration are developed by introducing the variable

p^T power production by the pass-out turbine
and the parameter

η_p^T the efficiency, i.e. power per unit fuel, of condensing production by a pass-out turbine.

We have from (2), the fuel requirement for back-pressure production by this turbine

$$f = \frac{p^{T+h}}{\eta_m} + \frac{(c_m+1)p^T}{c_m \eta_m} \quad \text{as } h = \frac{p^T}{c_m} \quad (14)$$

and the power production, when condensing production at the pass-out turbine is replaced by production at the marginal condensing turbine

$$p = p^T - \eta_p^T f + \eta_p f \quad \text{for } \eta_p^T > \eta_p \quad (15)$$

From (14) and (15) we have

$$f = \frac{(c_m+1)p}{c_m \eta_m - (c_m+1)(\eta_p^T - \eta_p)} \quad \text{as } p = (c_m - \frac{c_m+1}{\eta_m})(\eta_p^T - \eta_p)h \quad (16)$$

or

$$f = \frac{(c_m+1)h}{\eta_m} \quad \text{as } h = \frac{\eta_m}{c_m \eta_m - (c_m+1)(\eta_p^T - \eta_p)} \quad (17)$$

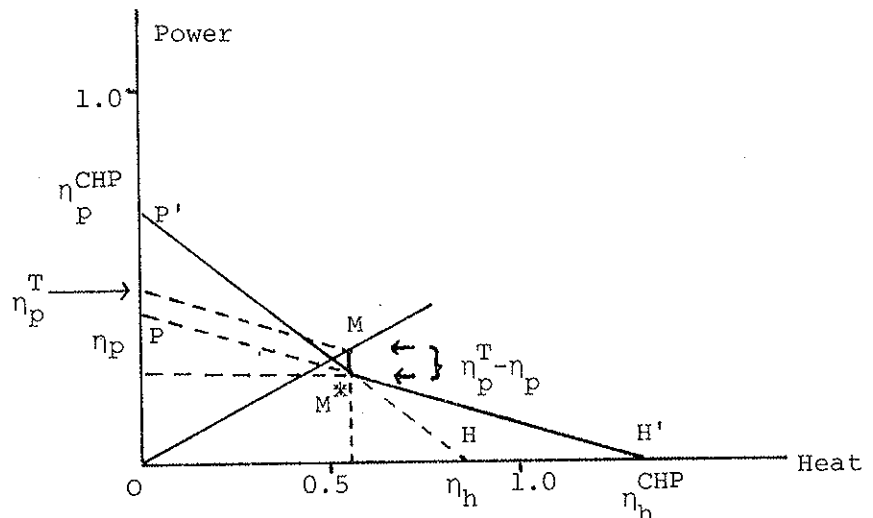
The efficiencies of cogenerated power and heat are derived from (16) and (17) respectively:

$$\eta_p^{CHP} = \left. \frac{\delta p}{\delta f} \right|_h = \frac{c_m \eta_m - (c_m+1)(\eta_p^T - \eta_p)}{c_m + 1 - \frac{\eta_m}{\eta_h}} \quad (18)$$

$$\eta_h^{CHP} = \left. \frac{\delta h}{\delta f} \right|_p = \frac{\eta_p}{c_v + \frac{(c_m+1)(\eta_p^T - \eta_p)}{\eta_m}} \quad (19)$$

For $\eta_p^T = \eta_p$ we get (7) and (12) from (18) and (19).

Figure 4. Power and heat produced by the marginal unit of fuel, within the capacity limit of cogeneration of a pass-out turbine with non-marginal condensing production in a system of interconnected conversion plants.



B. 5. Application by the DES-model.

In table 1 the parameters for some existing and planned Danish power stations are shown. Some of these parameters

Table 1. Turbine parameters of various power stations, and the efficiency of heat producent by CHP for different values of the efficiency of the marginal condensing turbine in the system.

	Turbine parameters				System parameters and derivatives 1)		
	c_m	η_p^T	η_m	η_p^{GHP}	η_p	η_h^{CHP}	c_v
1 Planned pass-out turbine (e.g. 300 MW electricity)	0.58	0.40	0.84	0.64 ²⁾ 0.74 ²⁾ 0.83	0.31 0.36 0.41	2.8 2.4 2.2	0.11 0.15 ²⁾ 0.19
2 Modern back-pressure turb. (15-80 MW electricity)	0.40		0.84	0.84	0.31 0.36 0.41	2.7 1.8 1.5	0.12 0.20 0.28
3 Existing pass-out turbine (e.g. 125 MW electricity)	0.68	0.37	0.76	0.51 ²⁾ 0.59 ²⁾ 0.66	0.31 0.36 0.41	3.9 2.8 1.8	0.08 ²⁾ 0.13 ³⁾ 0.22
4 Pass-out turbine rebuild from condensing turbine (e.g. 250 MW electricity)	0.41	0.40	0.83	0.53 ²⁾ 0.57 ²⁾ 0.78	0.31 0.36 0.41	1.5 1.5 1.5	0.23 ³⁾ 0.25 ³⁾ 0.29
5 Old pass-out turbine (e.g. 30 MW electricity)	0.15	0.26	0.79	0.55	0.31 0.36 0.41	0.98 0.97 0.92	0.32 0.37 0.44
6 Planned small gas turbines (e.g. 5 MW electricity)	0.39		0.90	1.06	0.31 0.36 0.41	3.5 2.2 1.7	0.09 0.17 0.24
7 Modern condensing turbine (e.g. 600 MW)		0.40					
8 Old condensing turbine (e.g. 40 MW)		0.25					

1) The parameter η_h is constant 0.85

2) Corrected when $\eta_p^T > \eta_p$ (otherwise a turbine parameter, which is derived from c_m , η_m and η_h) cf. (18)

3) Corrected when $\eta_p^T > \eta_p$

are used in the simulation of the electricity generating system and for the space heating system.

The priority list according to the variable expenses, which is an essential feature of the simulation of the electricity generating system, is set up by increasing values of fuel costs plus operating cost per kWh produced. Since the variable operating costs are negligible the priority list is derived from

$$\frac{\text{fuel price}}{\eta_p^T \text{ or } \eta_p^{\text{CHP}}}$$

for condensing or back-pressure production respectively.

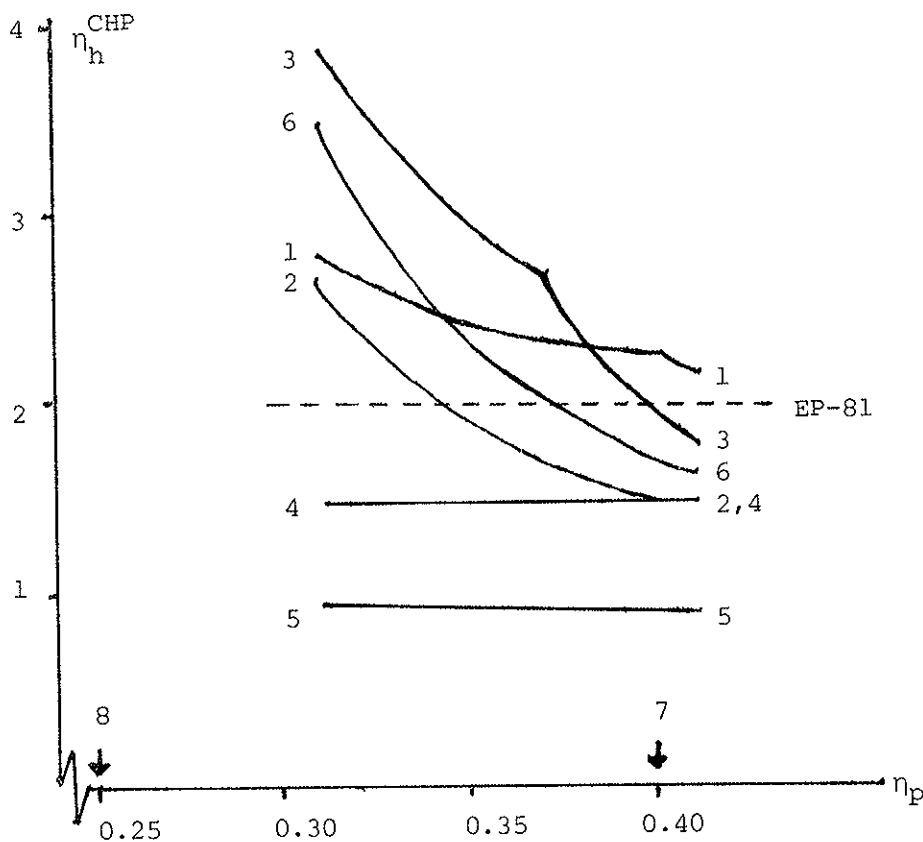


Figure 5. Efficiency of cogenerated heat for various turbines as a function of the efficiency of the marginal condensing turbine in the electricity generating system. The numbers refer to the power stations in table 1.

The simulation model calculates the total variable expenses of the power production and the primary fuel requirement for power production. The total primary fuel requirement for the power stations involved is calculated by adding

$$\frac{\text{cogenerated heat}}{\eta_h}$$

and the expenses are calculated by multiplication with the price of the fuel used by the power stations.

The primary fuel requirement and the fuel expenses, which are assigned to the cogenerated heat for the space heating system, however are calculated from

$$\frac{\text{cogenerated heat}}{\eta_h^{\text{CHP}}}$$

and the same price of fuel.

In other words: The benefit of cogeneration must first be given to the individual power station for economic dispatching among power stations: Thereafter the benefit of cogeneration is given to cogenerated heat for the evaluation of district heating schemes with CHP-supply, when the efficiency of CHP is to be compared with other forms of heating.

The efficiency of cogenerated heat, η_h^{CHP} , can vary drastically as seen from table 1 and figure 5, depending on the producing unit and the efficiency of the marginal condensing unit, η_p . The latter parameter may be found by studying the simulation of the electricity generating system within the DES-model.

The determination of η_h^{CHP} is in practice extremely complicated and therefore for simplicity, it was chosen to use the traditional value $\eta_h^{\text{CHP}} = 2.0$ in the EP81 study for all years in the planning period.

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<p>55 pages + tables + illustrations</p>	
<p>Abstract</p> <p>The DES-model is designed for a long-term description of the Danish energy system. Given the demand for useful energy in various sectors, and given development plans for the conversion and distribution system, the annual primary energy requirement is calculated, together with the costs for fuel, investment, operation and maintenance. In this report we present a survey of the main features of the program for the model, and a description of the model-structure which was used for the Danish Energy Plan 1981. The essential parts of this model are (1) the simulation of the electricity generating system which includes combined heat and power, and (2) the structure and the efficiencies of the space heating system.</p> <p>Available on request from Risø Library, Risø National Laboratory (Risø Bibliotek), Forsøgsanlæg Risø), DK-4000 Roskilde, Denmark Telephone: (02) 37 12 12, ext. 2262. Telex: 43116</p>	<p>Copies to</p>

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